Weather Associated with the Fall-2000 Turbulence Flight Tests

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Outline

- Introduction
- Flight Experiments
  - Equipment for turbulence detection
  - Flight requirements
  - Flight preparations
- Turbulence Metrics
- Research Flights
- Summary

Turbulence Threat

- Sudden, unexpected encounters with turbulence, usually lasting 10-30 seconds, have led to frequent injuries aboard commercial aircraft
- A recent study of 44 turbulence encounters resulting in injuries:
  - 82% were found to be near or within convective activity
  - Mountain wave (2%), CAT (16%)

Purpose

- **Test turbulence sensors & their hazard algorithms**
  - ***In situ***
  - **Radar**
- **Provide data for developing/testing detection algorithm**
- **Provide data for model validation**
- **Provide data for turbulence characterization**

Flight Experiments

- **NASA-Langley's ARIES B-757 flew into regions favorable for convectively-induced turbulence**

- **ARIES equipment**
  - ***In situ* sensors measure wind, temperature and acceleration**
  - **Onboard Doppler radar for forward turbulence detection**

- **Data collected for events ranging from smooth air to severe turbulence**

Flight Requirements

- Flight days were chosen based on likelihood of convectively-induced turbulence within flight range of NASA Langley
  - Test days limited by availability of B-757
- Altitudes of interest: between 18,000 and 40,000 ft
- Direct penetration into regions with Level 3 radar reflectivity were avoided

Flight Preparations

- Meteorology team at NASA-Langley prepared: 2-day, 1-day, and day-of forecasts in support of flight tests
  - Brief researchers
  - Brief pilots for flight planning
- Products Used:
  - NCEP models, i.e. RUC, ETA, etc.
  - NC State's operational mesoscale model
  - Airmets, Pireps, NCAR's ITFA
  - Satellite and Radar
- Meteorologist on board provided guidance into turbulent regions

Turbulence Metrics

- **Quantification of *in situ* turbulence:**
  - **Root mean square of normal load acceleration: $\sigma_{\Delta n}$**
  - **Eddy dissipation rate: $\varepsilon^{1/3}$**

- **Defined a significant turbulence event as:**

$$\sigma_{\Delta n} > 0.15$$

  - **$\sigma_{\Delta n} > 0.20$ moderate**
  - **$\sigma_{\Delta n} > 0.30$ severe**

The Flight Experiments

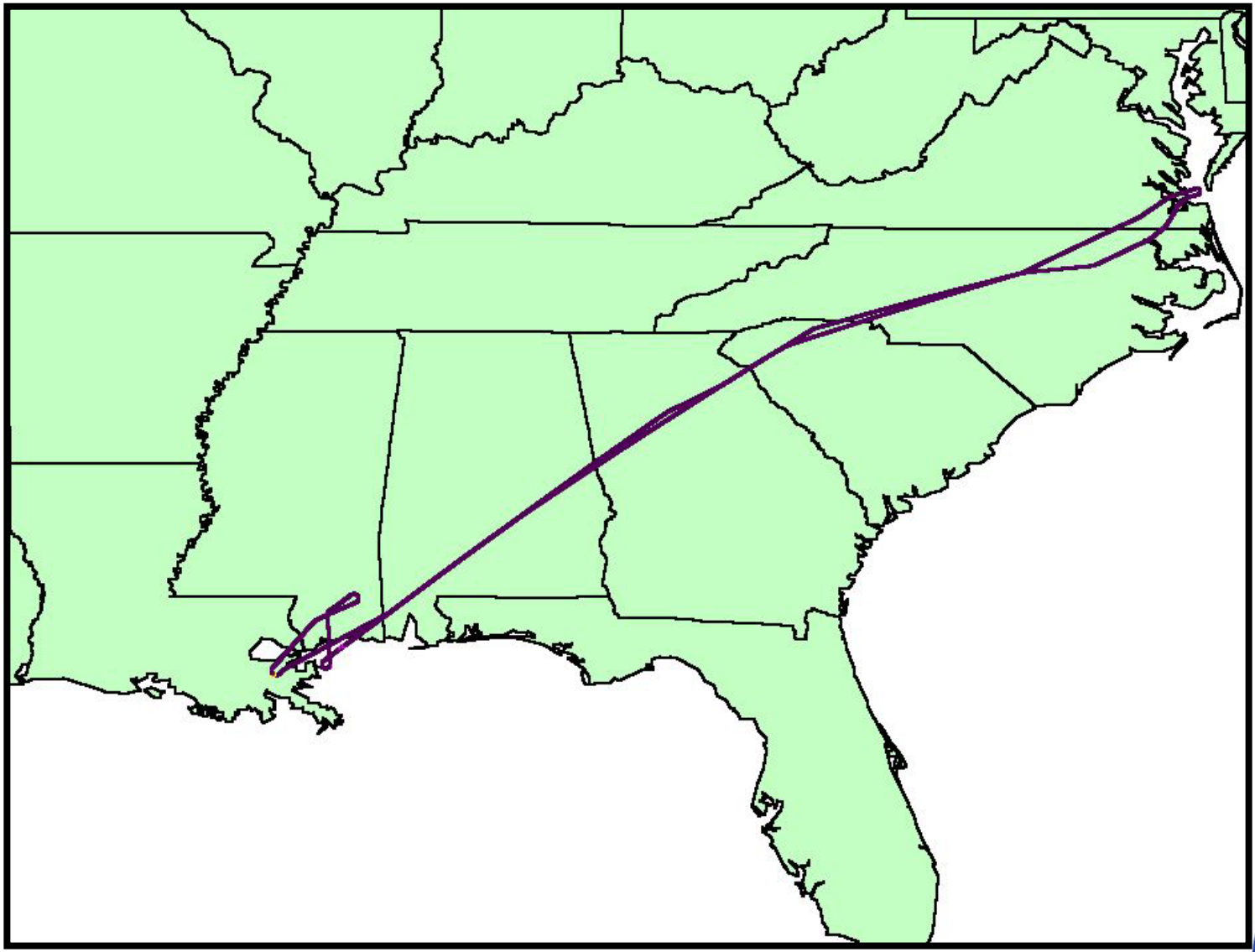
- R-181, November 16, 2000
- R-190, December 13, 2000
- R-191, December 14, 2000

Flight Day	Weather	Primary Region of Interest	Peak Storm Tops (k ft)	Cell Movement (from)	# of Events w/ Sign. Turb.	Peak *In Situ* Turbulence $\sigma_{\Delta n}$	$\varepsilon^{1/3}$ ($m^{2/3}/s$)
R 181 16 Nov 2000	Broad Area of Rain w/ Embedded Convective Cells	S. Miss. & La.	30	WSW at 45 kts	3	0.21	0.44
R 190 13 Dec 2000	Broad Area of Rain & Convective Cells w/ Embedded T'storms	NE La.	43	SW at 65 kts	2	0.35	0.78
R 191 14 Dec 2000	Narrow Line of Convective Cells/ T'storms	Florida Pan. & S. Georgia	40	SW at 40 kts	2	0.44	0.84

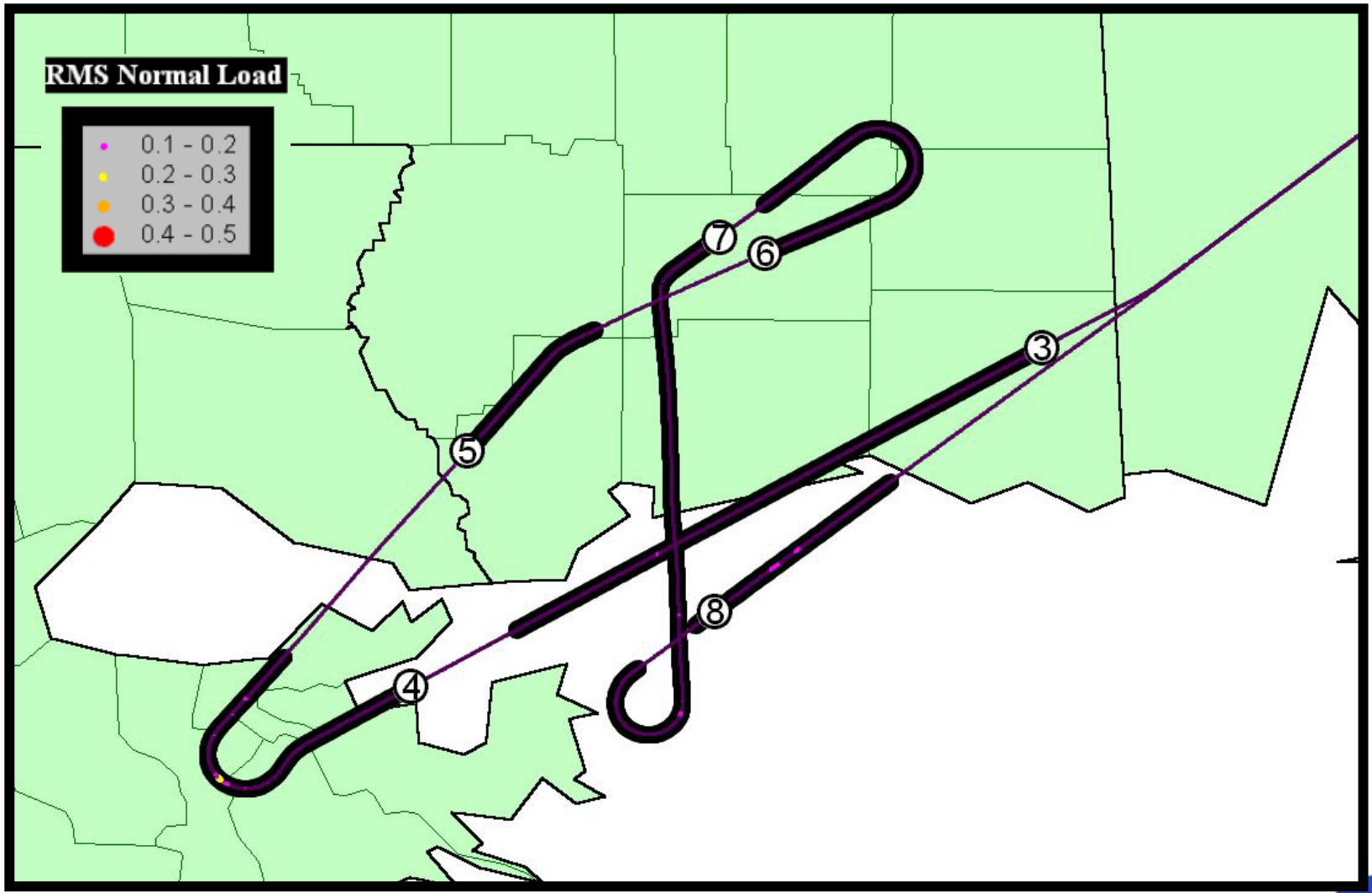
R 181 – Nov 16, 2000

- **Mississippi-Louisiana Gulf Coast region favorable for convective turbulence**
- **Broad overrunning of rain with embedded convective cells**
  - **Peak storm top: 30,000 *ft***
  - **Cell movement: from west-southwest at 45 *kts***
- **3 significant turbulence events with peak *in situ* measurement:**
  - $\sigma_{\Delta n} = 0.21$
  - $\varepsilon^{1/3} = 0.44$

Flight Path for 181

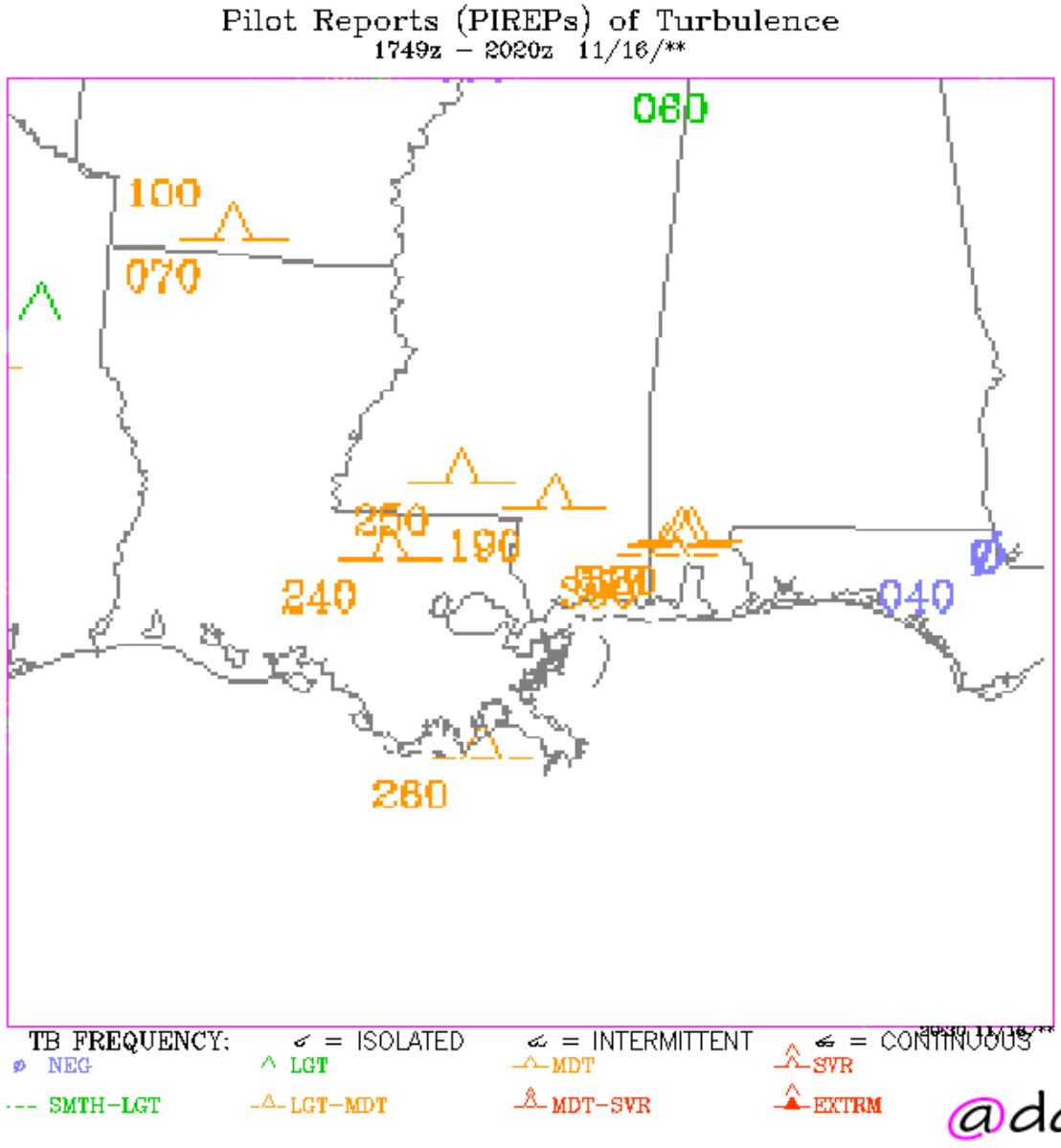


Flight Path 181 – RMS Normal Loads



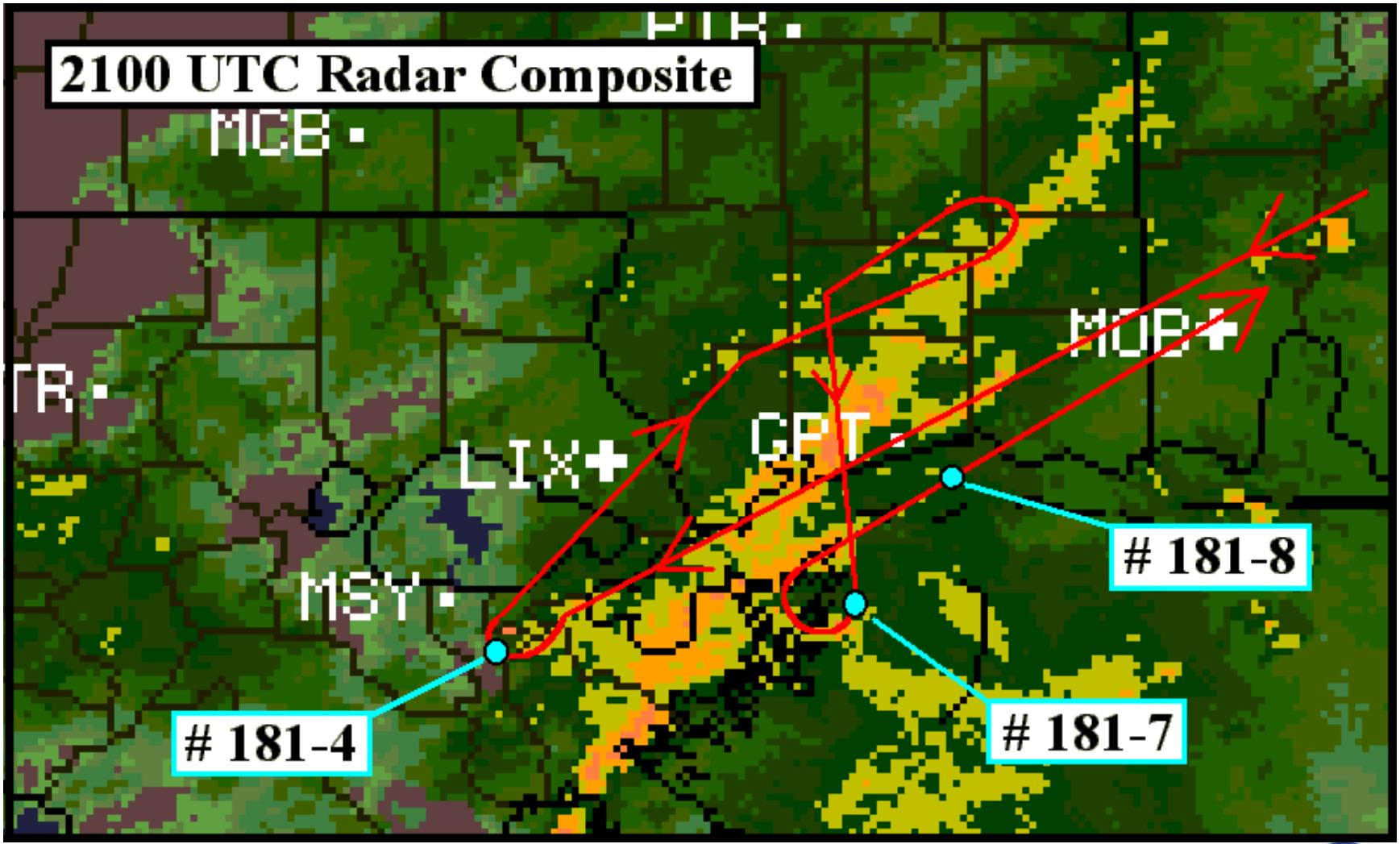
Reported PIREPS on Nov. 16, 2000

1749 – 2020 UTC

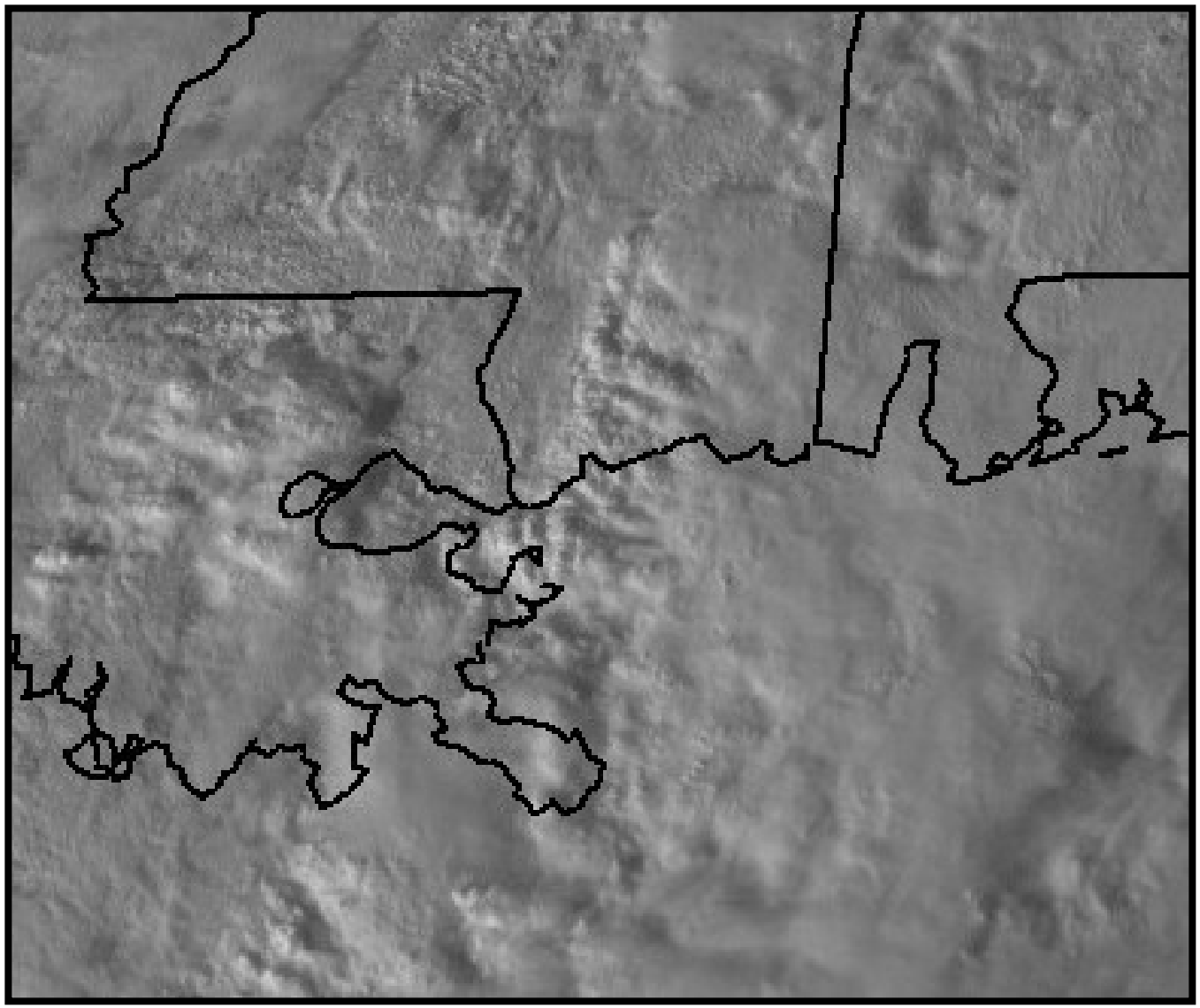


@dds

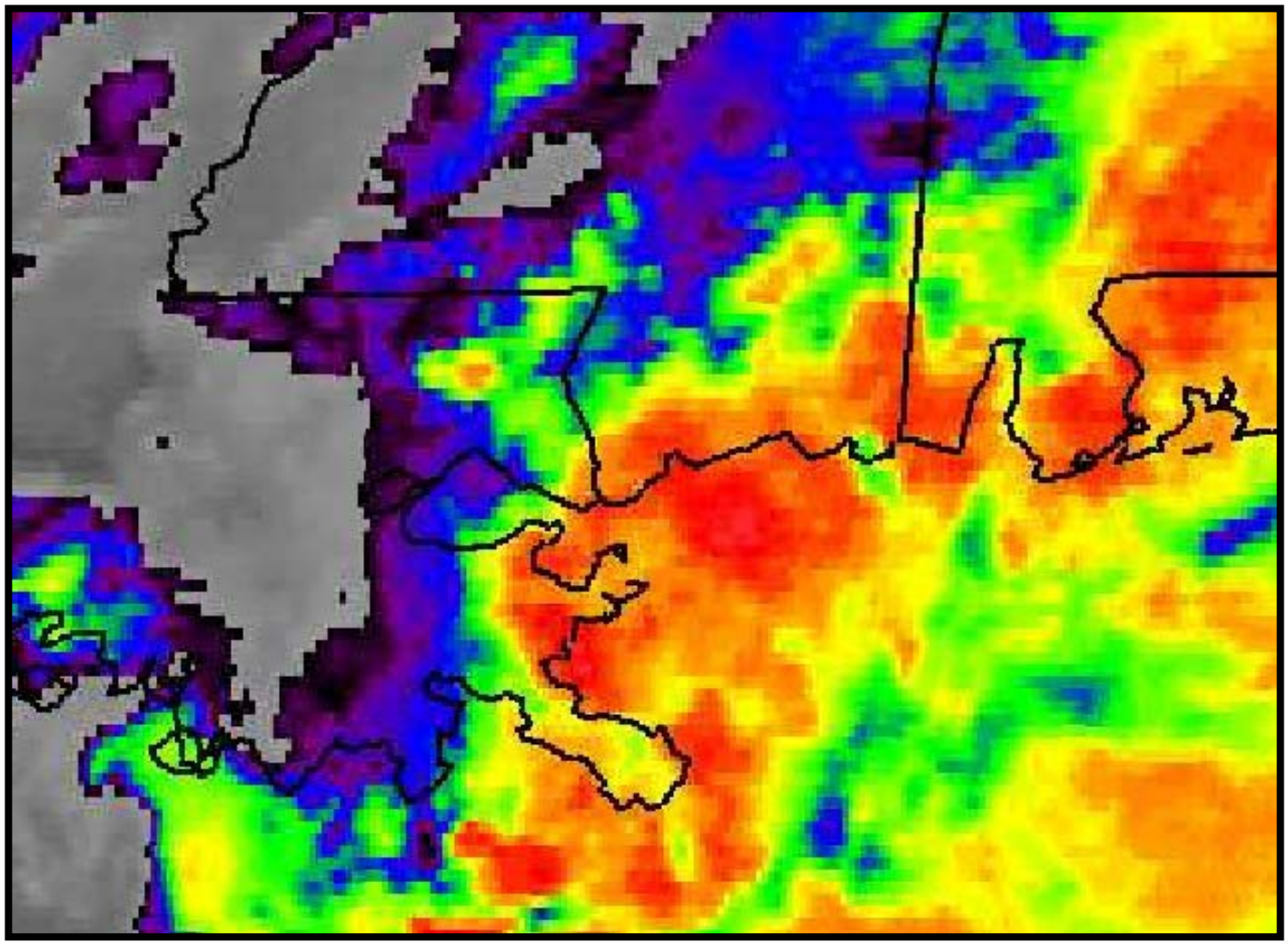
Flight 181 – Path with Nowrad



1 km Resolution Visible Satellite
2115 Z November 16, 2000



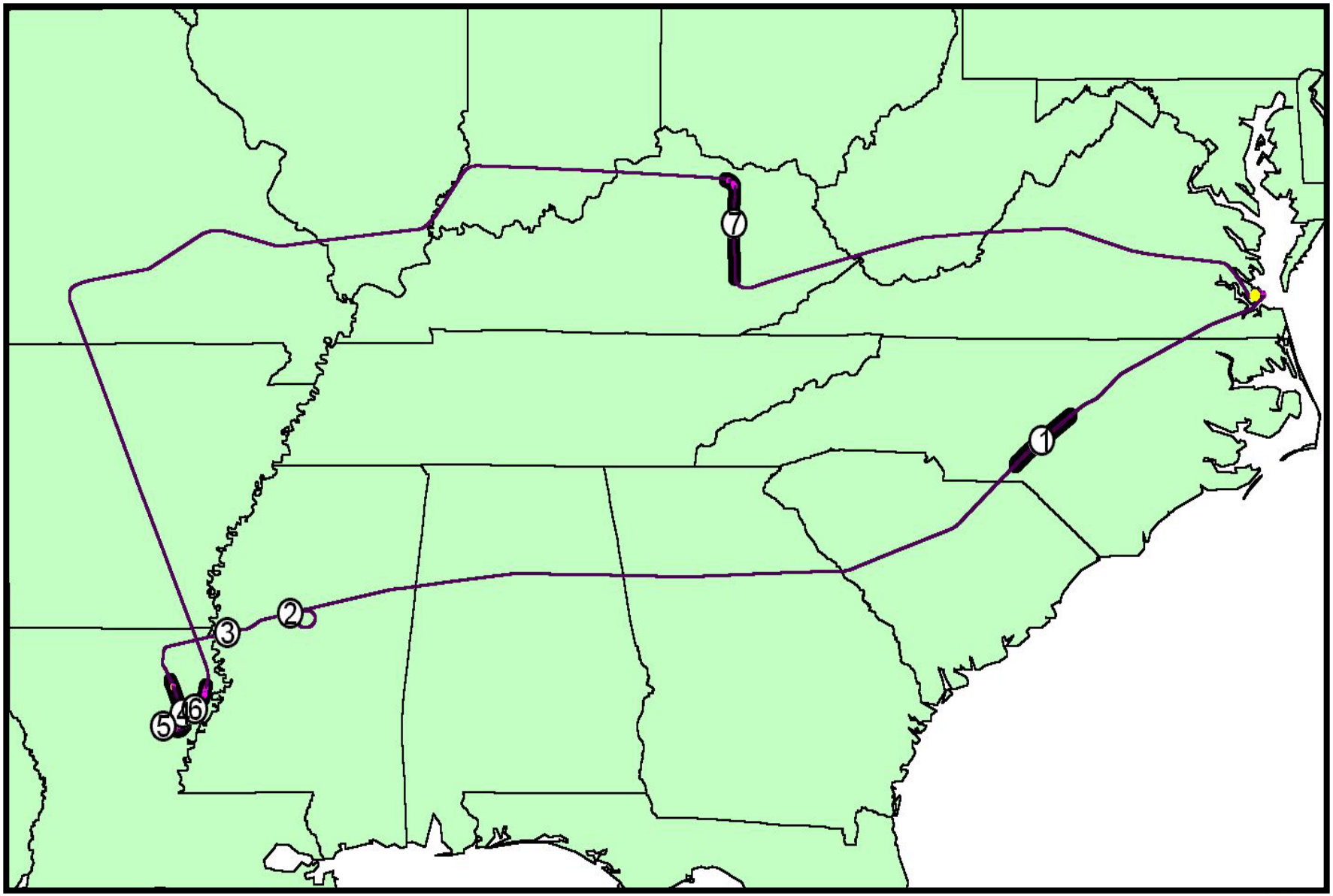
4 km Resolution Infrared Satellite
2015 Z November 16, 2000



Event	Altitude (MSL) (k ft)	Peak *In Situ* Turbulence $\sigma_{\Delta n}$	Peak *In Situ* Turbulence $\varepsilon^{1/3}$ ($m^{2/3}/s$)	Peak Vertical Wind (m/s) *from 1Hz data Max	Peak Vertical Wind (m/s) *from 1Hz data Min	Horizontal Scale/ Duration of Event	Peak Radar Reflectivity (along flight path)
181-4	22	0.21	0.44	3.5 m/s	-3 m/s	undetermined	NA
181-7	19	0.15	0.30	5.5 m/s	-1 m/s	undetermined	25 dBz
181-8	19	0.16	0.35	5.5 m/s	-2 m/s	10 km / 60 sec	27 dBz
190-4	24	0.28	0.73	11.5 m/s	-6.5 m/s	10 km / 60 sec	20 dBz
190-6	24	0.35	0.78	15 m/s	-3 m/s	1.5 km / 6 sec	23 dBz
191-3	33	0.34	0.80	6 m/s	-15 m/s	7 km / 30 sec	35 dBz
191-6	33	0.44	0.84	17 m/s	-12 m/s	3.5 km / 15 sec	33 dBz

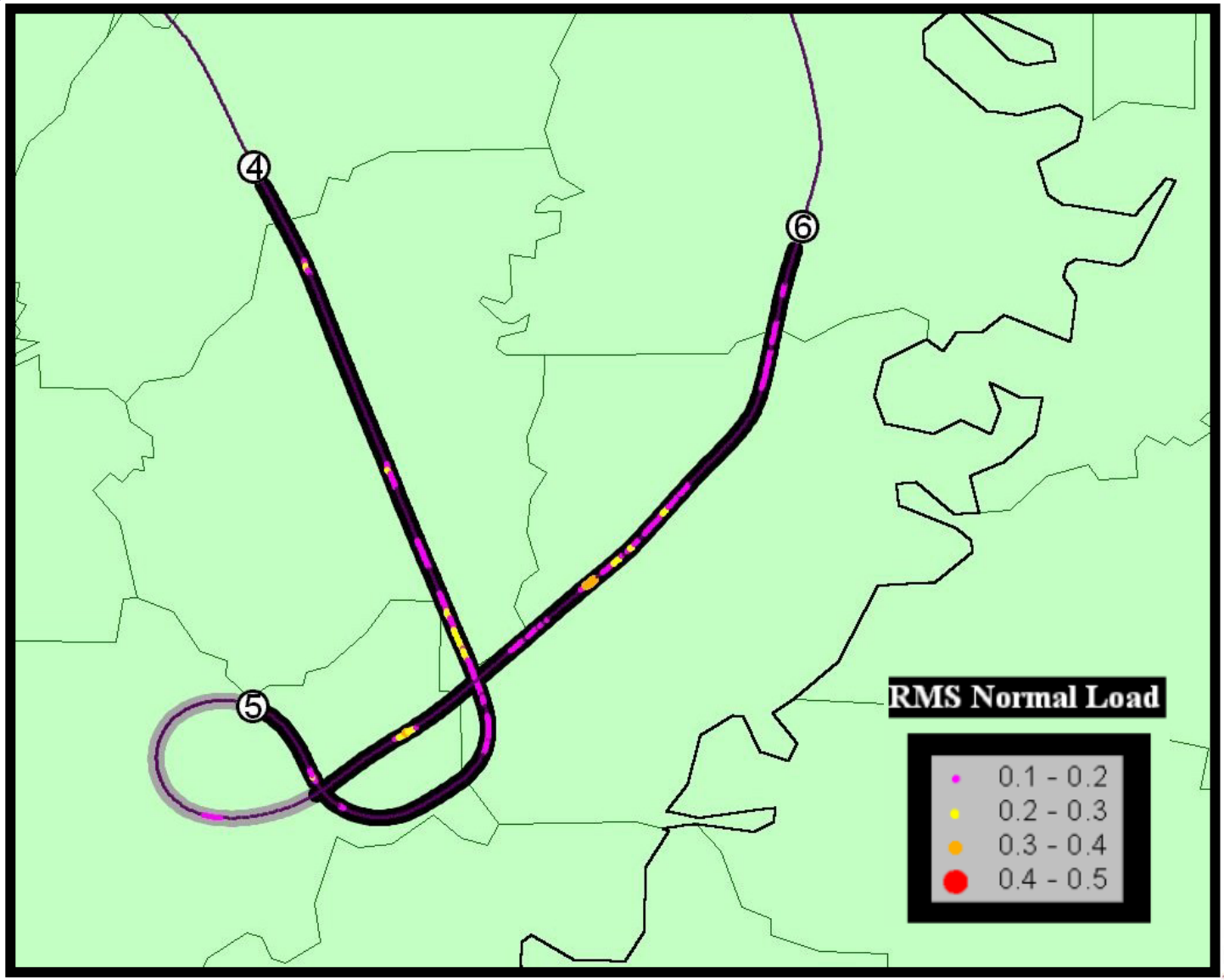
R – 190 December 13, 2000

- Along Gulf Coast; convective turbulence experienced in Central Mississippi and NE Louisiana
- Broad overrunning area of rain and convective cells with embedded thunderstorms
  - Peak storm tops: 43,000 *ft*
  - Cell movement: from southwest at 65 *kts*
- 2 significant turbulence events with peak *in situ* measurement:
  - $\sigma_{\Delta n} = 0.35$
  - $\varepsilon^{1/3} = 0.78$

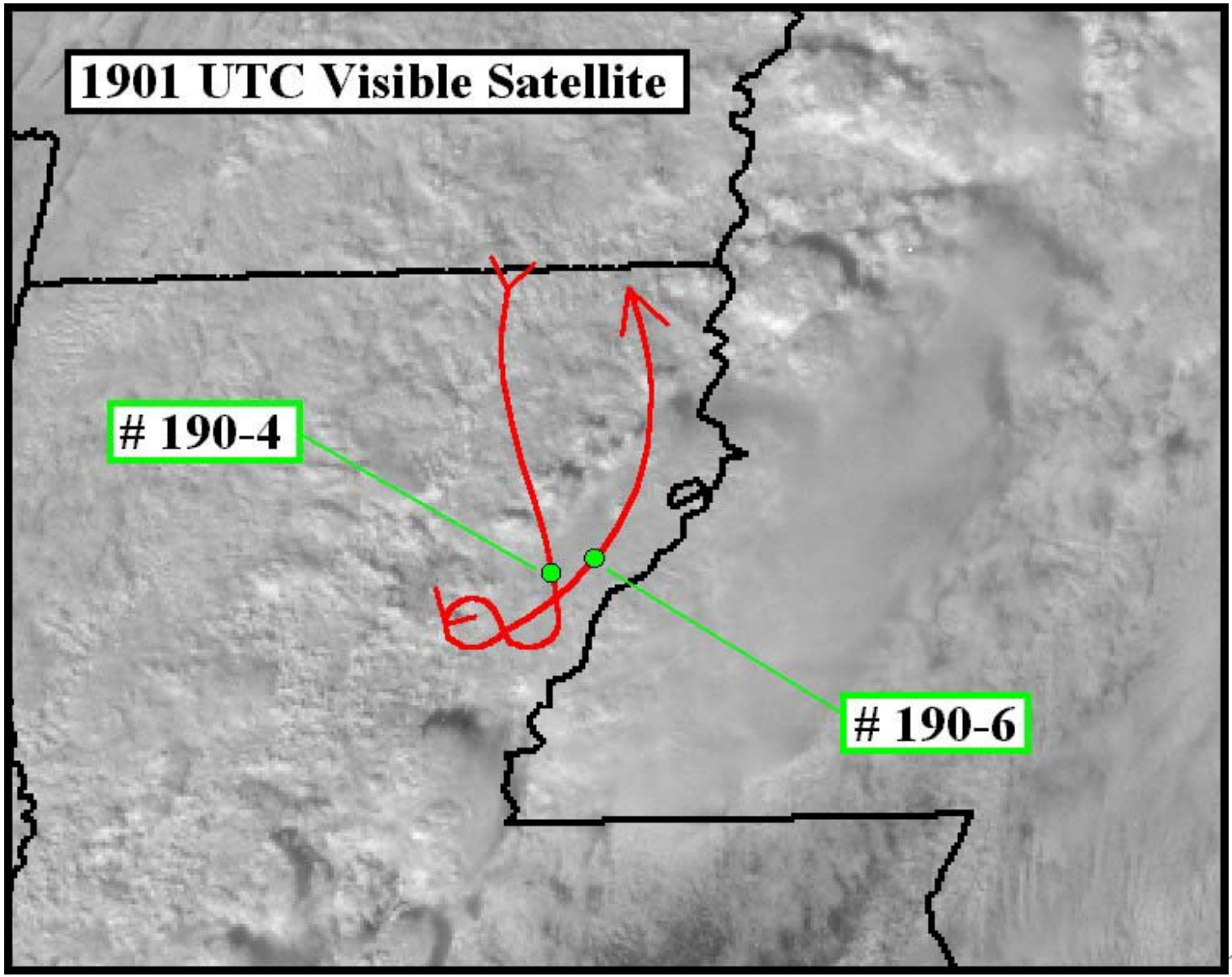


Flight 190 Dec. 13, 2000

Flight Path 190 – RMS Normal Loads



Flight 190 – Path with Satellite



On Edge of Convection

On Edge of Convection (cont.)

Event	Altitude (MSL) (k ft)	Peak *In Situ* Turbulence $\sigma_{\Delta n}$	Peak *In Situ* Turbulence $\varepsilon^{1/3}$ ($m^{2/3}/s$)	Peak Vertical Wind (m/s) *from 1Hz data Max	Peak Vertical Wind (m/s) *from 1Hz data Min	Horizontal Scale/ Duration of Event	Peak Radar Reflectivity (along flight path)
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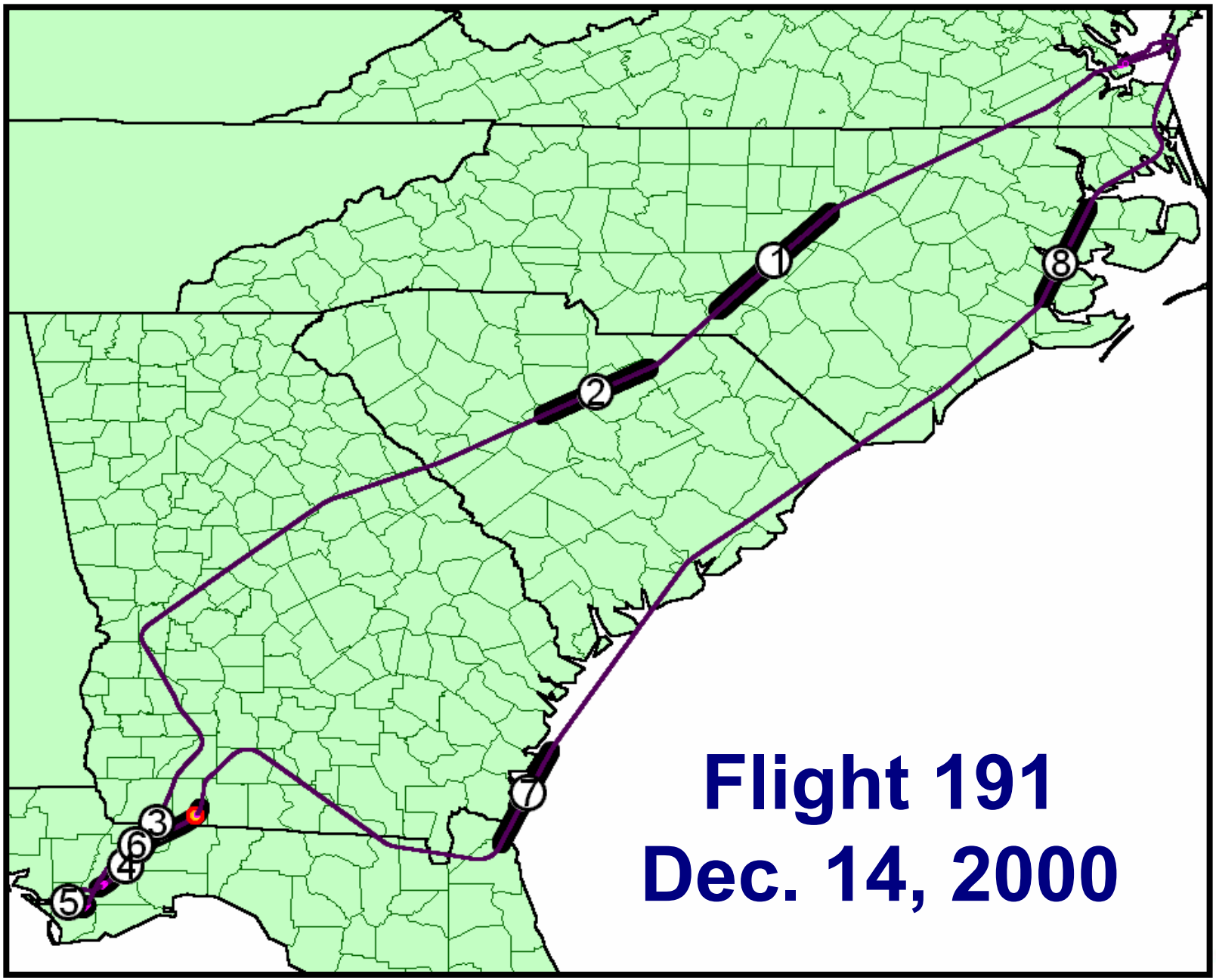
190-6	24	0.35	0.78	15 m/s	-3 m/s	1.5 km / 6 sec	23 dBz
191-3	33	0.34	0.80	6 m/s	-15 m/s	7 km / 30 sec	35 dBz
191-6	33	0.44	0.84	17 m/s	-12 m/s	3.5 km / 15 sec	33 dBz

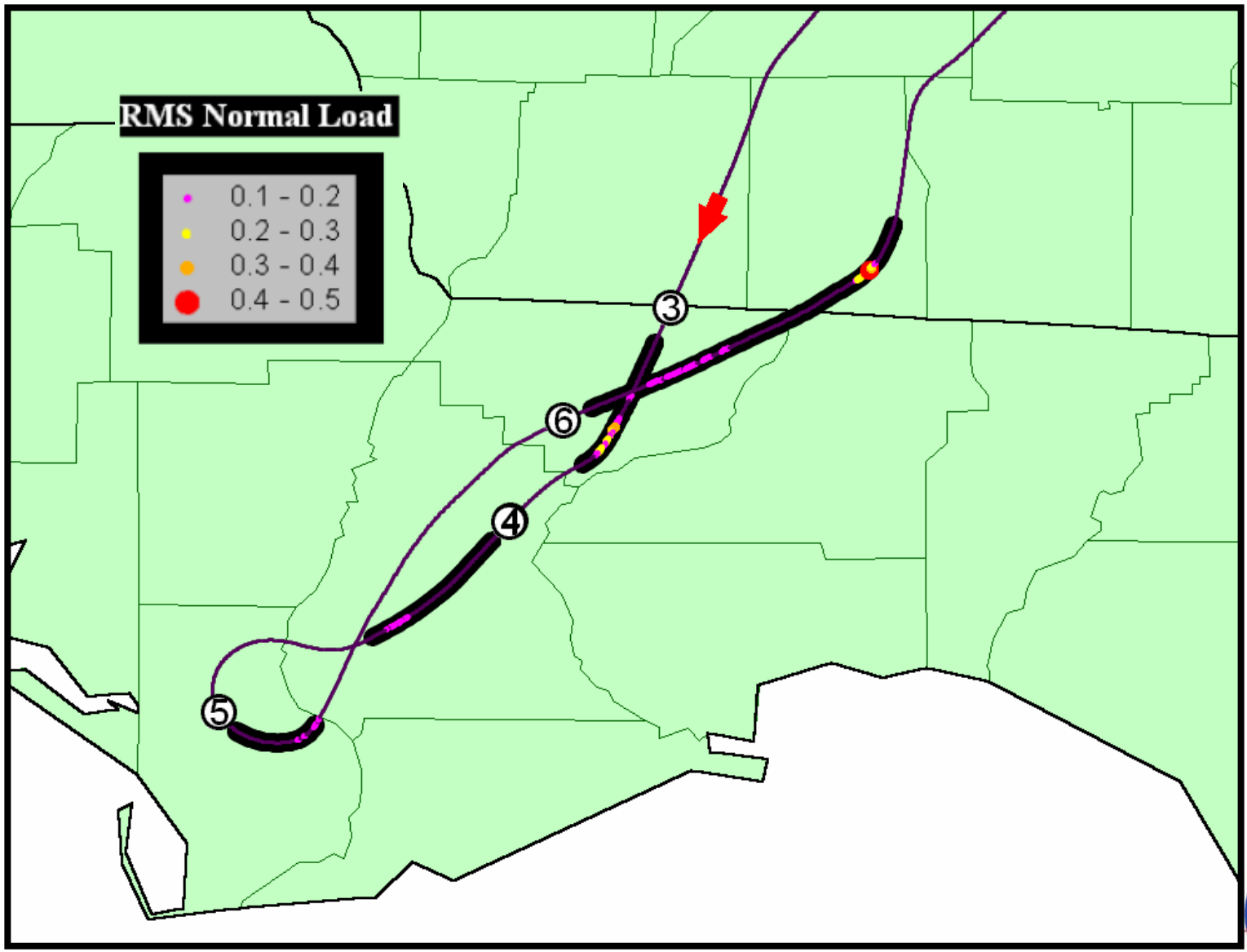
R – 191 December 13, 2000

- S Georgia and N Florida Panhandle; turbulence experienced near Tallahassee, Fl and Valdosta, Ga
- Narrow line of convective cells
  - Peak storm tops: 43,000 *ft*
  - Cell movement: from southwest at 65 *kts*
- 2 significant turbulence events with peak *in situ* measurement:
  - $\sigma_{\Delta n} = 0.35$
  - $\varepsilon^{1/3} = 0.78$

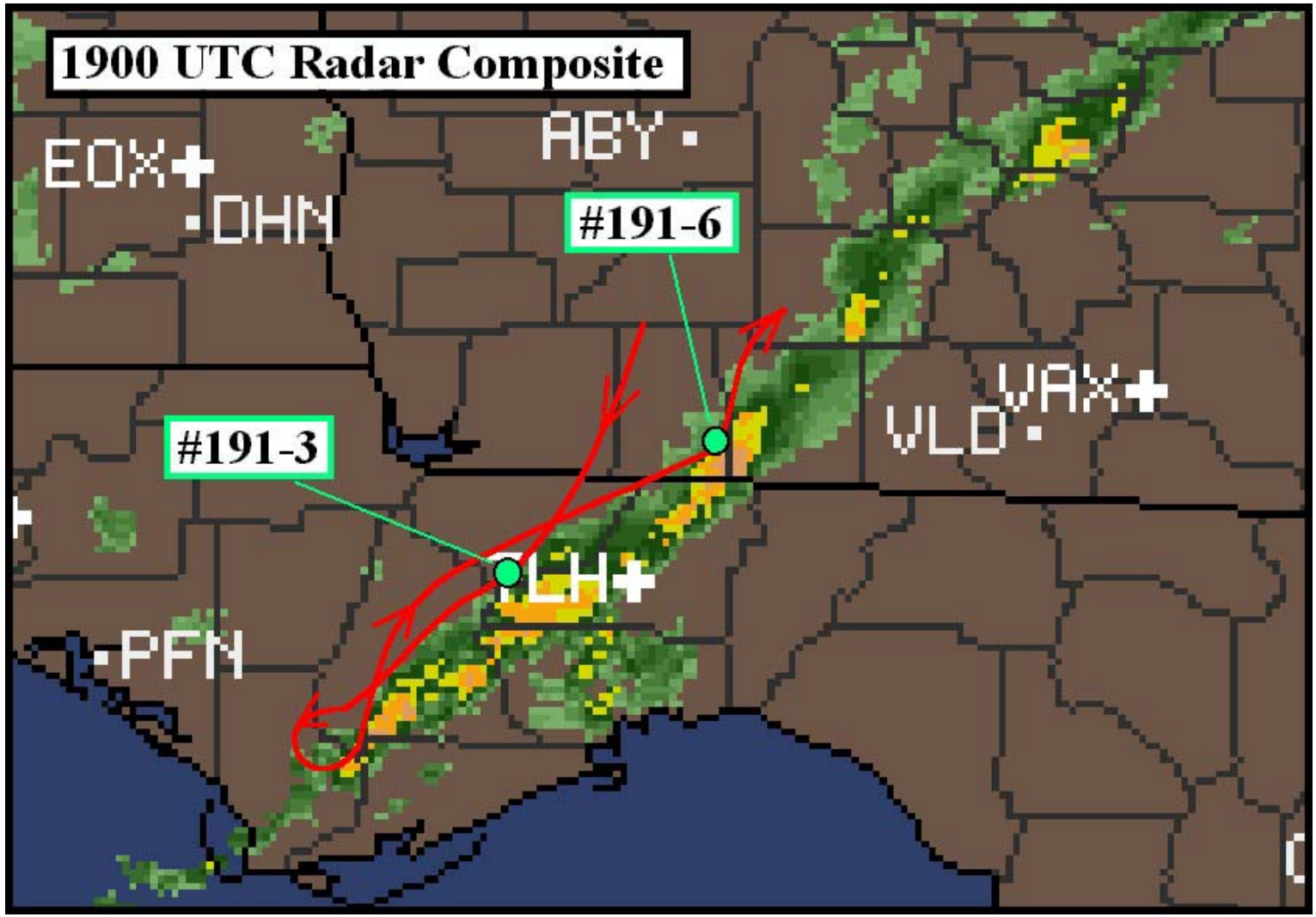


Flight 191
Dec. 14, 2000

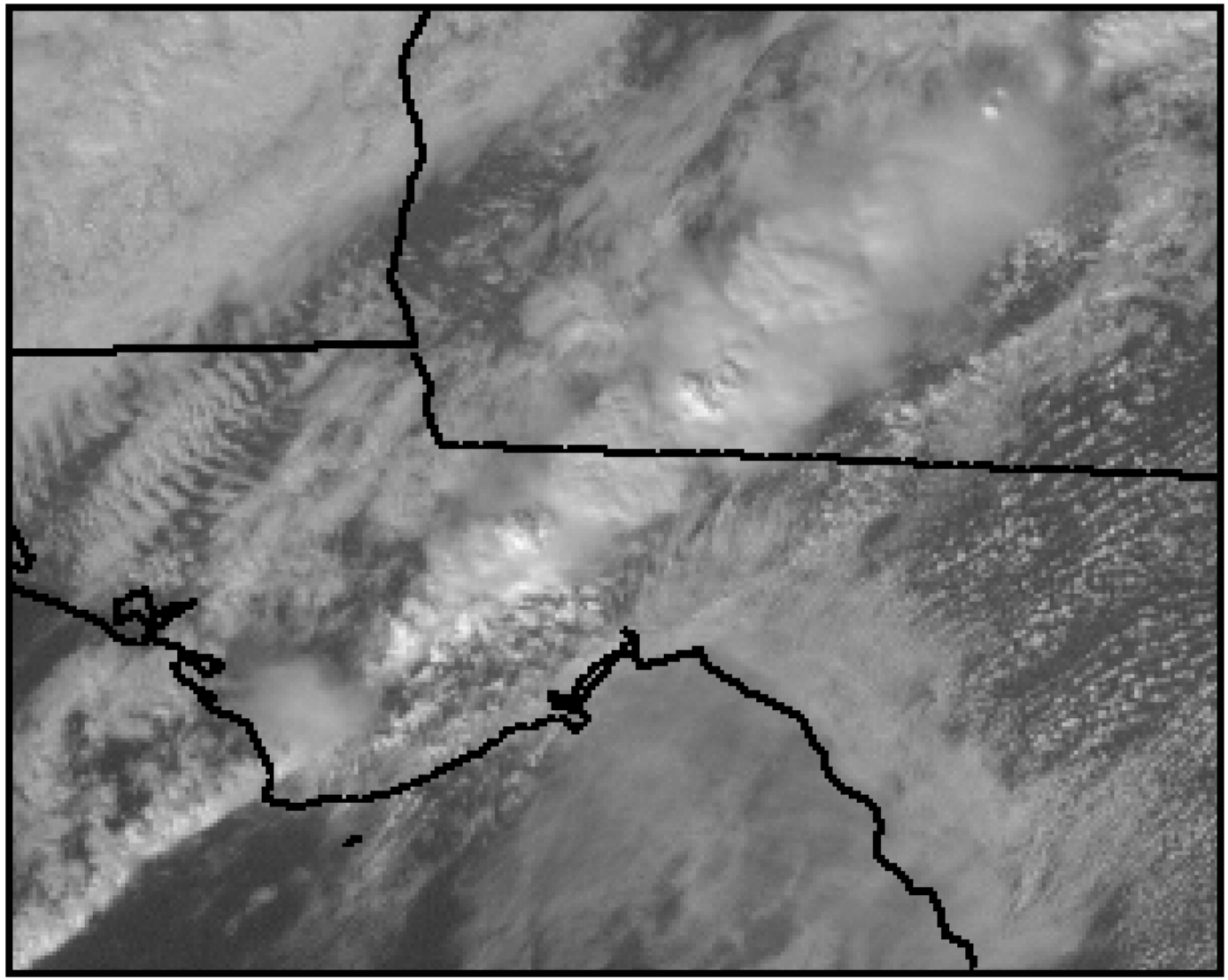
Flight Path 191 – RMS Normal Loads



Flight 191 – Path with Nowrad

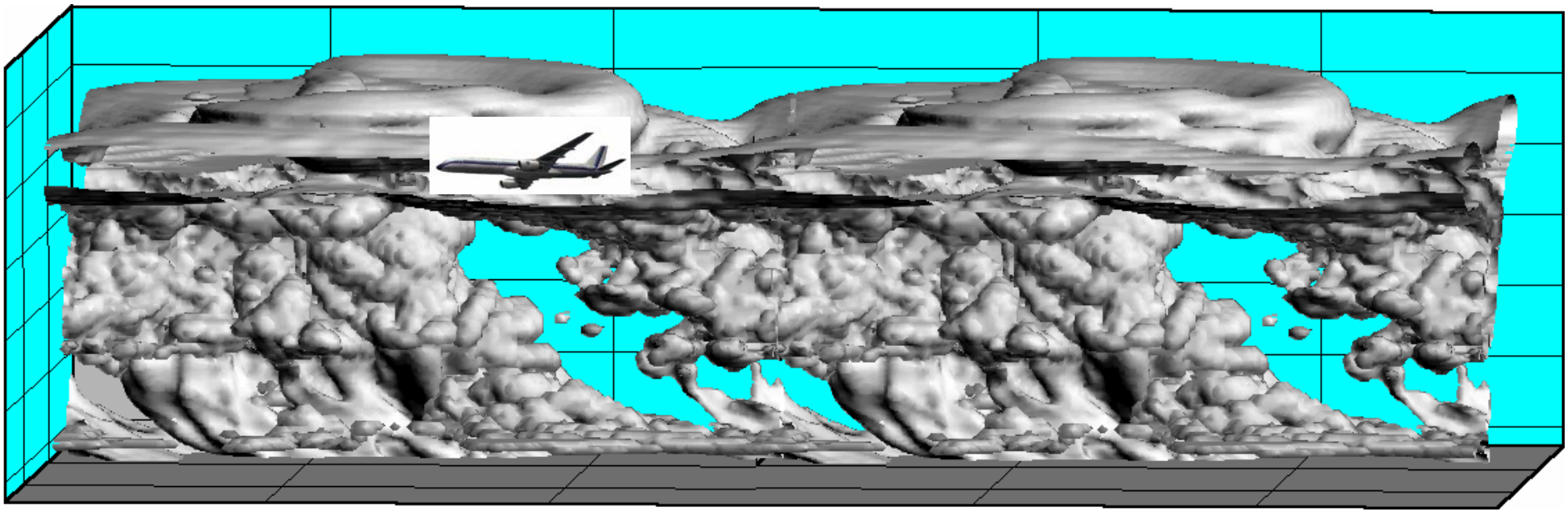


1 km Visible Satellite
1845 Z December 14, 2000



On Approach to Convection

TASS 100 m Simulation



Event	Altitude (MSL) (k ft)	Peak *In Situ* Turbulence $\sigma_{\Delta n}$	Peak *In Situ* Turbulence $\varepsilon^{1/3}$ ($m^{2/3}/s$)	Peak Vertical Wind (m/s) *from 1Hz data Max	Peak Vertical Wind (m/s) *from 1Hz data Min	Horizontal Scale/ Duration of Event	Peak Radar Reflectivity (along flight path)
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SUMMARY

- 3 flight experiments into regions favorable for convectively-induced turbulence
- 7 significant turbulence events
- 3 events considered severe turbulence (based on $\sigma_{\Delta n}$)